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(54) ULTRASOUND TRANSMITTING OR RECEIVING APPARATUS

(71) We, TOKYO SHIBAURA ELECTRIC COMPANY LIMITED, a Japanese corporation, of 72 Horikawa-cho, Saiwai-ku, Kawasaki-shi, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to ultrasound transmitting or receiving scanning apparatus in which an acoustic wave is electronically scanned, and more particularly to the apparatus adopting a sector scanning and a compound scanning in which the azimuthal directions of transmission or reception of an acoustic wave are changed by phase control during the electronic scanning of an acoustic wave.

There have been used apparatus in which ultrasound pulses are launched into the tissues and the boundary of the two different kind of tissues which have respectively different acoustic impedance reflects the pulses and the echo signals are utilized to image various planes of the tissues and to diagnose the diseased regions of the tissues.

The method used in the apparatus mentioned above is called pulse reflection method.

In the pulse reflection method, ultrasound pulses having a frequency of 2 MHz - 10 MHz are launched into the tissues from transducer elements and the acoustic waves reflected by a tissue boundary are detected for the diagnosis. This method is sub-divided according to the display system. More particularly, according to an A scope the reflected waves are observed as an amplitude variation on a cathode ray tube, whereas according to a B scope the reflected waves are observed as a two-dimensional tomographic images represented by the variation in the brightness of a cathode ray tube by steering the ultrasound beam through a plane of

the tissue structure under investigation by traveling a transducer. Furthermore, the method is also sub-divided regarding the scanning system. In the linear scanning system, an ultrasound beam is steered in a parallel format and in the sector scanning system, the beam is steered in a circular sector format. According to a compound scanning system, the linear scanning system and the sector scanning system are combined.

Such ultrasound transmitting or receiving apparatus utilizing the pulse reflection method is at present used to diagnose the presence or absence of the bleeding in a brain caused by a head injury, various types of tumors, cholelithiasis and obstetrics. Especially, the sector scanning system is suitable for generating tomographic images of the heart. Therefore, ultrasound transmitting or receiving apparatus for practical use is strongly required.

In the electronic scanning type ultrasound transmitting or receiving apparatus, when the pulses having the delay times expressed by $(n-1)d\sin\theta$, $(n-2)d\sin\theta$... 0, where θ represents the azimuthal angle in radians of an ultrasound beam, d the center to center distance between adjacent transducer elements, c the sound velocity (1,500 m/sec) in the medium, n the number of the transducer elements, are applied a number of the transducer elements which comprise an array of the transducer elements, the wavefronts of the ultrasound pulses generated by respective transducer elements align on a straight line A-A₁ shown in Fig. 1, thereby transmitting an ultrasound beam in the direction of θ .

During reception, echoes returning from targets in the direction of the transmitted pulses arrive at the transducer elements at different times. This necessitates a delay of the received signal so that the effective orientation of the transducer elements array during reception corresponds to the orientation during transmission.

Accordingly when the echo signals received by respective transducer elements are summed by a summing amplifier in phase after applied with the delay times just the same as the times applied to the transmitted pulses, the acoustic waves received in the direction of θ can be detected as the strong signal, or as the summed echo signal from a desired azimuthal orientation. This signal is amplified by an amplifier, processed by a signal processing circuit and displayed by a display device.

In the sector scanning, amounts of relative delay times applied to each transducer elements are sequentially varied so as to scan by changing the azimuthal direction θ of transmission or reception of ultrasound beam.

Accordingly, in sector scanning, it is important to apply a correct amount of delay time to each transducer elements.

In order to change the azimuthal direction of the ultrasound beam the delay circuit should alter the time delay in each transducer elements. Moreover, as the echo signal passes through the variable delay circuit as an electrical analog signal the variable delay circuit should be an analogue delay circuit. Among delay lines that can satisfy these requirements may be mentioned an LC delay line.

It, therefore, has been tried to use a tapped LC delay line, but the error of the delay time of such delay line is large so that it can not be used in practice. When the tapped LC delay line is manufactured to have accurate delay time by decreasing the error, the delay line becomes extremely bulky and very expensive.

Where the delay time is accurately adjusted, the frequency characteristic becomes irregular, while the error of the delay time becomes large when the frequency characteristic is made to be flat.

For example, assume now that the spacing between adjacent transducer elements $d=0.5\text{mm}$, the number of the transducer elements $n=32$, and the azimuthal angle of the ultrasound beam $\theta=0.5^\circ\sim 40^\circ$, the delay time between transducer elements would be from 3 nano sec. to 6.6 microseconds. Thus, the ratio between the minimum delay time and the maximum delay time would be 2,000. Since the delay time is in the range of such wideness mentioned above, it may be represented in terms of a quantum delay time. The method of quantizing the delay time has been used in radar field, especially in phased array antenna system or the like. Strictly saying, in the case of the antenna, the quantum object is not the delay time but the phase, as is commonly recognized in the art. The quantization in the phased array antenna is described in detail in Skolnik, "Radar Handbook" published by McGraw-Hill Inc., 1970, pages 11-35 and

11-43.

Where the quantum delay time is expressed by τ , all the necessary delay times can be quantized and interchangeable to approximate values which are integer multiples of τ . The quantum delay time τ should be less than $1/10\sim 1/20$ of the period T_0 (reciprocal of frequency f_0) of the ultrasound pulse. Accordingly, the absolute error of the delay time of the delay circuit must be less than $T_0/10\sim T_0/20$.

For example, where the frequency of the ultrasound pulse $f_0=2.5\text{ MHz}$, and the absolute error of the delay time is equal to $T_0/16$, then the period $T_0=400\text{ nano sec.}$ so that less than $T_0/16=25\text{ nano seconds}$ is necessary for the error of the delay time. Expressing the allowable error time in terms of the relative error,

$$\frac{25\text{ nano sec.}}{6,600\text{ nano sec.}} \times 100 = 0.38\%.$$

The relative error accuracy of a commercial LC delay line necessary to obtain a delay time of the order of several microseconds is ordinarily about $\pm 2\%\sim\pm 5\%$. With this accuracy, therefore, the error of the delay time is large so that it is difficult to obtain high quality tomographic images due to the errors in the azimuthal direction of transmission or reception of ultrasound beam, and also due to the large side lobe which represents the transmission or reception of ultrasound beam in the directions except main beam.

Among the ultrasound receiving apparatus provided with the delay circuits comprising tapped LC delay lines, it has been proposed to connect in cascade a number of delay circuits for obtaining a composite reflected signal as shown in Fig. 2.

In this regard, reference is made to paper "Receiving System of Electronic Sector Scanning System", presented before Japan Ultrasound Medical Society, May, 1976.

According to this system, reflected acoustic waves received by transducer elements $T_1, T_2 \dots T_n$ are summed by passing then through delay circuits $D_1, D_2 \dots D_n$ and summing amplifiers $SA_1, SA_2 \dots SA_n$ and then displayed by a display device 14 through an amplifier (12) and a signal processing circuit 13 after modulating the brightness, as shown in Fig. 2. In this apparatus, the delay times of the delay circuits $D_1, D_2 \dots D_{n-1}$ are adjusted to be equal so as to obtain an ultrasound beam in the direction of θ (ultrasound azimuthal direction).

As the azimuthal angle θ varies, the delay times of the delay circuits $D_1, D_2 \dots D_{n-1}$ vary to effect scanning.

With this apparatus, it is difficult to accurately match the absolute values of the delay times.

Accordingly, the azimuthal direction of reception might be different from the correct

direction of the target.

For this reason, in such apparatus when different delay circuits are used for the transmission and reception of the acoustic wave, the azimuthal directions of transmission and reception often differ, thus substantially widening the beam width. Although not shown in Figure 2 it is necessary to connect buffer amplifiers between adjacent delay lines. Since such amplifiers cause additional time delays, it is necessary to insert further correction delay circuits between transducer elements $T_1, T_2 \dots T_n$ and the summing amplifiers $SA_1, SA_2 \dots SA_n$ for the purpose of compensating for such time delays thus requiring various circuits. Moreover, as the plurality of delay circuits such as 16 or 32 circuits are connected in cascade the frequency characteristics of the delay circuits $D_1, D_2 \dots D_{n-1}$ are greatly degraded whereby it became impossible to obtain a flat frequency characteristic.

Accordingly, it is an object of this invention to provide improved ultrasound transmitting or receiving scanning apparatus in which at least one of the various described defects of the prior art apparatus is alleviated.

According to one aspect of this invention, there is provided ultrasound transmitting or receiving scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line, a plurality of variable delay circuits for applying predetermined delay times to driving signals for driving said transducer elements or receiving signals received by said transducer elements, and a scanning control circuit for controlling the directions of transmission or reception of ultrasonic waves by specifying delay times of said variable delay circuits wherein, each of said variable delay circuits comprises tapped analogue delay lines; switches for selecting the taps of said delay lines; and a memory device having a plurality of addresses corresponding to the directions designated by said scanning control circuit, position information of the delay times provided by taps of said delay lines being so stored in the locations of the memory designated by said addresses that predetermined delay times may be selected.

According to another aspect of this invention there is provided ultrasound transmitting or receiving scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line, a plurality of variable delay circuits for applying predetermined delay times to driving signals for driving said transducer elements or receiving signals received by said transducer elements, and a scanning control circuit for controlling the directivities of transmission or reception of ultrasonic waves by specifying delay times of said variable delay

circuits, wherein each of said variable delay circuit comprises tapped analogue delay lines; switches for selecting the taps of said delay lines; and a memory latch circuit for storing output information from said scanning control circuit and said scanning control circuit comprises: a read only memory device having a plurality of addresses corresponding to the directions or ultrasound transmission or reception, position information of the delay times provided by taps of said tapped analogue delay lines being so stored in the locations of the memory designated by said addresses that predetermined delay times may be selected; a direction command generating circuit for generating that address information of said read only memory device corresponding to the direction of the ultrasonic waves; and a write latch command circuit for supplying a write latch pulse to said memory latch circuit of said variable delay circuits.

According to a further aspect of this invention there is provided ultrasound scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line to transmit and receive ultrasonic waves, one or more driving circuits for driving said transducer elements, a plurality of variable-delay circuits corresponding to said respective ultrasound transducer elements for applying predetermined delay times to the output of said driving circuits and to signals received by said transducer elements, a scanning control circuit for applying signals to said respective variable-delay circuits to designate the directivity of transmission or reception of ultrasonic waves, means for displaying the received signal passed through said variable-delay circuits, received by said ultrasound transducer elements, each of said variable delay circuits comprising tapped analogue delay lines, switches for selecting the taps of said delay lines, and a memory device having a plurality of addresses corresponding to the directions of transmitting and receiving the ultrasonic wave and in which are stored positions of taps of said tapped analogue delay lines which give delay times sufficiently closest to the predetermined delay times.

According to still a further aspect of this invention there is provided ultrasound scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line to transmit and receive ultrasonic waves; one or more driving circuits for driving said transducer elements; a plurality of variable delay circuits corresponding to said respective ultrasound transducer elements, and having tapped analogue delay lines for applying predetermined delay times to the output of said driving circuits and to signals received by said transducer elements; switches for selecting the taps of

said delay lines; a memory latch circuit for storing tap positions information; and a scanning control circuit having a read only memory device having a plurality of addresses corresponding to the directions of transmitting and receiving the ultrasonic waves in which are stored the position information of taps of said tapped analogue delay lines which give delay times closest to the predetermined delay times; a direction command generating circuit for supplying addresses corresponded to the directions of transmitting and receiving said ultrasonic waves; and a write latch command generating circuit which supplied write latch pulse to said memory latch circuit.

Embodiments of this invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 is a block diagram for explaining electronic sector scanning;

Fig. 2 is block connection diagram showing prior art sector scanning type ultrasound diagnosing apparatus;

Fig. 3 is a block diagram showing one way of applying this invention to an ultrasound diagnosing apparatus;

Fig. 4 is a block diagram showing a transmitting and receiving wave control circuit;

Figs. 5a to 5f are time charts of the transmitting and receiving wave control circuit;

Fig. 6 is a block diagram showing a scanning control circuit;

Fig. 7 is a connection diagram showing a portion of the embodiment shown in Fig. 3;

Fig. 8a is a graph for explaining the relationship between the deflection angle θ of the ultrasound beam and the addresses of a memory device corresponding to the deflection angle θ ;

Fig. 8b is a graph showing the relationship between the deflection angle θ and the delay time of respective transducer elements;

Fig. 9 is a block diagram showing the manner of storing the combinations of the taps of tapped delay lines in a read only memory device; and

Fig. 10 is a block diagram showing a modified embodiment of this invention.

Ultrasound transmitting or receiving apparatus applied to the ultrasound diagnosing apparatus will now be described.

Referring now to Fig. 3, 32 transducer elements TR_1 through TR_{32} are arranged in a line to transmit ultrasound pulses and to receive reflected ultrasonic waves. Respective transducer elements are connected to the output terminals of driving pulse generators DP_1 to DP_{32} and input terminals of limiters L_1 to L_{32} through cables. The output terminals of these limiters L_1 through L_{32} are connected to the input terminals of corresponding preamplifiers PA_1 to PA_{32} . The output terminals of these preamplifiers PA_1 to PA_{32} , the output terminal of a reference

signal generator 31 and the input terminals of delay circuits DC_1 to DC_{32} are connected to respective analogue switches S_1 to S_{32} of a switch group 35. In response to a control signal generated by a transmitting and receiving wave control circuit 36, respective variable delay circuits (hereinbelow referred to as delay circuit) DC_1 to DC_{32} receive a reference pulses generated by a reference signal generator 31 or reflected ultrasound signals which have passed through preamplifiers PA_1 to PA_{32} . The analogue switches SW_1 to SW_{32} of the switch group 37 are controlled by the output signal of the transmitting and receiving wave control circuit 36 to be transfer switched in synchronism with switches S_1 to S_{32} of switch group 35. Thus, when the input terminals of the delay circuits DC_1 to DC_{32} are connected to the output terminal of reference signal generator 31, the output terminals of these delay circuits are transferred to the input terminals of driving pulse generators DP_1 to DP_{32} , whereas when the input terminals of the delay circuits DC_1 to DC_{32} are connected to the output terminals of respective preamplifiers PA_1 to PA_{32} , the output terminals of the delay circuits DC_1 to DC_{32} are connected to the input terminal of an amplifier 32 via resistors R_1 to R_{32} .

The relationship between the transmitting and receiving wave control circuit 36 and switch groups 35 and 37 will now be described. More particularly, as shown in Fig. 4, one output terminal of the reference signal generator 31 is connected to the input terminal of a monostable multivibrator 41 while the other output terminal is connected to an analogue switch S_1 of the switch group 35. The output terminal of the monostable multivibrator 41 is connected to control terminal of the analogue switch S_1 . Type SPOT analogue switch (DG186) sold by Siliconix Inc. is suitable as the switch shown in Fig. 4. The output terminal of the monostable multivibrator 41 is connected to control terminal of an analogue switch SW_1 of a switch group 37 via an inverter 45. Furthermore, the common terminals of the analogue switches S_1 and SW_1 are connected to delay circuit DC_1 .

Since the transmitting and receiving wave control circuit 36, the analogue switches S_1 through S_{32} and switches SW_1 through SW_{32} of the switch groups 35 and 37 are constructed as above described, the operation of the transmitting and receiving wave control circuit 36 will now be described with reference to Figs. 5a to 5f.

When the output signal generated by the reference signal generator 31 becomes high level as shown in Fig. 5a, the output of the multivibrator 41 becomes high level as shown by Fig. 5b, and upper contact I of the analogue switch S_1 becomes ON state as shown in Fig. 5e so that the analogue switch

5 S_1 is throwing to upper contact I. However, the output of the inverter 45 becomes low level as shown in Fig. 5f thus throwing the analogue switch SW_1 to lower contact II. Consequently, the drive pulse generator DP_1 produces a pulse as shown in Fig. 5c. When a received wave signal as shown in Fig. 5d is applied to the preamplifier PA_1 the output of the monostable multivibrator 41 becomes low level whereas the output of the inverter 45 becomes high level. As a consequence, the analogue switch S_1 is thrown to the lower contact II and the analogue switch SW_1 to the upper contact I.

15 The received ultrasound signals are summed together by the resistor circuits ($R_1, R_2 \dots R_n$), amplified by amplifier 32 and then detected by the signal processing circuit 33. The construction and operation of the signal processing circuit 33 is described in detail in P.N.T. Wells, "Physical Principle of Ultrasonic Diagnosis" Academic Press (1969), page 108, Figs. 4, 12.

20 The signal processed by the signal processing circuit 33 is displayed by display device 34.

25 The operating timing of the transmitting and receiving wave control circuit 36, the scanning control circuit 38, the signal processing circuit 33 and the display device 34 is controlled by the signal generated by the reference signal generating circuit 31. The delay times of the input signals provided by the delay circuits DC_1 to DC_{32} are controlled by the scanning control circuit 38 which is constituted by binary counters 61 and 62 in the simplest form as shown by Fig. 6.

30 Where transmitting acoustic waves and receiving the echo signals from 256 different azimuthal directions, the simplest construction comprises two binary counters 61 and 62, each containing 4 bits are connected in series and their outputs are supplied to 8 bit input terminals r_1 to r_8 of a read only memory device 63. When a rate pulse generated by the reference signal generator 31 is applied to the binary counters 61 and 62, these counters count up one by one to designate repetition of codes 00000000, 00000001, 00000010 ... 11111111 as the addresses of the read only memory device 63, whereby 256 scanning lines are designated. Type SN74193 binary counter sold by Texas Instrument Co. is suitable as the 4 bit binary counters 61 and 62.

35 The manner of setting the delay times of delay circuits DC_1 to DC_{32} by the output signal of the scanning control circuit 38 will now be described with reference to Fig. 7 by taking one delay circuit DC_1 for one channel as an example.

40 As shown in Fig. 7, the delay circuit DC_1 comprises first and second tapped LC delay lines each provided with 16 output taps, first and second identical transfer switches 73 and

74 each provided with 16 input terminal respectively connected to the 16 output terminals of the delay line and one output terminal, a read only memory device 63 connected to 4 control input terminals A_1 to A_4 and B_1 to B_4 of respective transfer switches 73 and 74, and a buffer amplifier 75 connected between the output terminal of the first transfer switch 73 and the input of the second tapped LC delay line 72. Actually the circuit elements bounded by dot and dash lines are formed on the same printed circuit board.

45 The first tapped LC delay line 71 has 25 nano seconds intertap delay time so that its delay time can be varied in a range of from 0 to 375 nano seconds by the transfer operation of the first transfer switch 73, and its error is ± 10 nano seconds for the maximum delay time of 375 nano seconds. The relative error of the delay time is $\pm 2.7\%$ and a delay line having such accuracy can readily be manufactured.

50 The second tapped LC delay line 72 has an intertap delay time of 380 nano seconds which is substantially equal to the maximum delay time of the first tapped LC delay line 71. The intertap delay time error of the delay line 72 is about ± 10 nano seconds which is variable in a range of from 0 to 5.7 microseconds. The delay line 72 has an error of ± 150 nano seconds for the maximum delay time of 5.7 microseconds, that is a relative error of $\pm 2.6\%$. Such delay line can also be readily manufactured.

55 Type DG506 transfer switch manufactured by Siliconix Inc. is suitable as the first and second transfer switches 73 and 74. The transfer of respective switches C_1 to C_{16} and D_1 to D_{16} (corresponding to output taps of the delay lines) of the transfer switches 73 and 74 is controlled by a binary signal supplied to the control input terminals A_1 through A_4 and B_1 through B_4 from the read only memory device 63.

60 The contents of this memory device are written as follows.

65 Thus, optimum delay times are predetermined by an equation corresponding to respective azimuthal angles of the transmission and reception of the ultrasound, and respective addresses of the read only memory device are made to correspond to specific angles of the directions of acoustic wave transmission and reception. A control information is written into the read only memory device which controls the first and second transfer switches 73 and 74 such that the first and second tapped LC delay lines 71 and 72 produce delay times which are closest to the optimum delay times.

Although in the foregoing description, the delay circuit DC_1 was described the same is true for the other delay circuits DC_2 to DC_{32} .

Since the intertap delay times of the tap-

ped delay lines 71 and 72 have errors depending on the delay lines used as above described, the contents of the read only memory device 63 of the same channel may differ depending upon an LC delay line employed.

For example, in the illustrated apparatus, where an ultrasound is transmitted and received in 256 different directions θ , the scanning control circuits 38 applies to the read only memory device 63 of respective delay circuits DC_1 to DC_{32} an 8 bit binary signal corresponding to respective angles of θ_{128} to $-\theta_{128}$ (total 256 angles). Each read only memory device applies the control input signals which have been stored in respective addresses to the control input terminals of the first and second transfer switches 73 and 74 whereby the delay circuits DC_1 through DC_{32} are controlled to generate delay times which are closest to correct delay time necessary to transmit and receive the ultrasonic wave in the designated directions.

For example, as shown in Fig. 8a, where an ultrasound beam is transmitted from an array of transducer elements TR_1 through TR_{32} in the direction of θ_{128} and the wave receiving directivity is in this direction (hereinafter termed deflection in the direction of θ_{128}), the output signal of the scanning control circuit 38 would be 00000000. At this time, in this address of the read only memory device 63 is stored a control signal showing a specific one of the first and second transfer switches 73 and 74 which gives a delay time which is closest to that required at that time.

As shown in Fig. 8b, where deflection is made in the direction of θ_{128} , the delay time applied to the transducer element TR_1 is the maximum. At this time, the read only memory device 63 of the delay circuit DC_1 produces a control signal that connects selectively the switches C_{16} and D_{16} of the first and second transfer switches 73 and 74.

However, as the first and second tapped LC delay lines 71 and 72 have errors respectively as above described, it is not always sure that delay lines 71 and 72 of the delay circuit DC_1 give delay times closest to the optimum delay time when switch positions C_{16} and D_{16} are transferred.

As above described the first and second tapped delay lines 71 and 72 have delay time errors of less than ± 150 nano seconds it is necessary to measure times when the switch terminals of the transfer switches 73 and 74 are connected to the taps of the delay lines 71 and 72 for storing combinations of the taps of the analogue switches that produce delay times closest to required delay times for respective angular directions in the addresses of the read only memory device corresponding to respective angles.

Where an electronic focusing (referred to USP 3,914,683, for example) is added to

sector scanning, the required delay time will be shown by one-dot-dash line in the azimuthal direction of θ_{128} in Fig. 8b. Though the electronic focusing delay times are generally added to electronic scanning, only the delay time for giving a directivity will be described hereinbelow.

Where a delay circuit including a combination of the read only memory device 63 storing the above described content, the tapped LC delay line and the transfer switch is used for the delay circuit DC_1 produce necessary delay times at sufficiently high accuracies with reference to the address of the read only memory device 63 irrespective of poor accuracy of the LC delay line itself.

The switch terminal number to be selected of respective transfer switches is stored in the read only memory device 63 in the following manner.

As shown in Fig. 9, delay circuits DC_1 to DC_{32} , circuit elements similar thereto, pulse generator 91, counter circuit I (92) counter circuit II (93), and an oscilloscope 94 are provided. The addresses of read only memory device 100 are constituted by 8 bits and its outputs are constituted by 10 bits.

Transfer of 32 switch terminal of the transfer switches 96 and 97 are controlled by 5 bit input signals. A buffer amplifier 95 is connected between the first transfer switch 96 and the second tapped delay line 99.

Each of the first and second tapped delay lines 98 and 99 is provided with 32 taps. The intertap delay time of the first tapped delay line 98 is 6.25 nano seconds, whereas that of the second tapped delay line 99 is 200 nano seconds. Furthermore, these delay lines are substantially free from any delay time error. Surface wave delay line can be used for this purpose.

The necessary delay times at sufficiently high accuracies produced by the first and second tapped delay lines 98, 99 will be displayed on the scope 94 and taps of the first and second tapped LC delay lines 71, 72 are selected in order to produce the same amounts of delay time.

The pulse generator 91 generates an impulse train having a repetition frequency of 1 KHz, for example. The counter circuit I 92 comprises 8 bits and its content is incremented one by one by a manually operated switch to designate the addresses of read only memory devices 100 and 63. The former stores the address of a switch terminal that gives a delay time closest to the delay time required by each address.

At first the counter circuit I (92) sets the address of the read only memory device 100 to 00000001. At this time, the terminals of the transfer switches 96 and 97 controlled by the output of the read only memory corresponding to this address 00000000 become ON state.

The impulse generated by the pulse generator 91 is delayed by correct delay time by delay line 98 and 99 and displayed on oscilloscope 94.

5 Then, the number of counts of the counter II (93) is manually adjusted so that the impulse displayed on the oscilloscope through delay line 71 and 72 would superpose upon the impulse through delay line 98 and 99, and the count of the counter circuit II (93) when these impulses coincide with each other is stored in an address of the read only memory device 63. Next, the switch of the counter circuit I (92) is operated to designate the next address 00000001 of the read only memory devices 100 and 63. In the same manner, suitable values are written in the read only memory device 63. The memory device which has been written with suitable values for the delay lines 71 and 72 utilized at that time in its 256 addresses is incorporated into the apparatus shown in Fig. 3 together with the transfer switches 73 and 74, and the delay lines 71 and 72 utilized at that time. Such operation described above is repeated by the times of the number of delay circuits i.e. 32 times and the read only memory devices stored the information in their addresses are mounted on the delay circuits.

30 Besides above described, there are various methods for writing suitable values to read only memory 63 such that datas obtained by measuring each intertap delay time (32 datas for each channel) of the tapped LC delay lines 71 and 72 accurately are proposed by a computer and the output of the computer is directly written into the read only memory 63.

40 The embodiment shown in Figs. 3 to 7 operates as follows.

The output signal of the transmitting and receiving wave control circuit 36 controls the switches of the switch group 35 such that they are thrown to the upper contacts and the switches of the switch group 37 such that they are thrown to the lower contacts.

45 The scanning control circuit 38 produces an 8 bits signal corresponding to the ultrasound azimuthal angle θ_{128} and each read only memory device 63 of each of the delay circuits DC_1 to DC_{32} designates the same address 00000000. The output signal from the read only memory device 63 designates a switch combination most suitable for the delay time applied to respective transducer elements TR_1 to TR_{32} for the first and second transfer switches 73 and 74. The designated terminals of the transfer switches 73 and 74 become ON state so that the pulse generated by the reference signal generator is applied to the driving pulse generators DP_1 to DP_{32} passing through the delay circuits DC_1 to DC_{32} , with suitable delay time, thus driving the transducer elements TR_1 to TR_{32} by the driving pulse generated by the driving

pulse generators DP_1 through DP_{32} with suitable delay time. Since the delay time decreases in the order of from delay circuit DC_1 to the delay circuit DC_{32} , the transducer elements are driven in the order of from TR_{32} to TR_1 with the result that the ultrasound beam is transmitted in the direction of θ_{128} .

70 Thereafter, the output signal from the transmitting and receiving wave control circuit 36 is applied through the switches of the switch groups 35 and 37 respectively to the lower and upper contacts. The reflected ultrasound signals received by the transducer elements TR_1 to TR_{32} are amplified by preamplifiers PA_1 to PA_{32} , delayed by delay circuits DC_1 to DC_{32} in the same manner as in the case of transmission and then summed. The azimuthal steering of the received acoustic wave is in the direction of θ_{128} .

85 Limiters L_1 to L_{32} limit high voltage transmitting pulses applied to the inputs of the preamplifiers PA_1 to PA_{32} .

90 The summed signal is amplified by amplifier 32, detected by signal processing circuit 33 and then displayed on display device 34 as a signal corresponding to the direction θ_{128} after has been subjected to brightness modulation.

95 The output signal from the transmitting and receiving wave control circuit 36 throws the switches of switch groups 35 and 37 to the upper and lower contacts respectively, while the scanning control circuit 38 produces an 8 bit signal 00000001 corresponding to θ_{127} . Suitable terminals of the first and second transfer switches 73 and 74 are selected by the output signal of the read only memory 63 to obtain a delay time corresponding to the direction of transmission θ_{127} of the ultrasound beam.

100 Thereafter, the reference pulse generated by the reference signal generator 31 is applied to respective driving pulse generators DP_1 to DP_{32} via delay circuits DC_1 to DC_{32} so that the transducer elements TR_1 to TR_{32} transmit the ultrasound beam in the direction of θ_{127} . In the same manner, scanning of the ultrasound is made until angle $-\theta_{128}$ is reached.

110 In this embodiment, the delay circuit is constituted by a first tapped LC delay line having a shorter overall delay time and a second tapped LC delay line having an intertap delay time substantially equal to the overall delay time of the first tapped LC delay line and a longer overall delay time, and further having lower absolute accuracy. By the use of two kinds of tapped LC delay line, it is possible to greatly decrease the number of taps than a case wherein the delay circuit is constituted by a single tapped LC delay line.

115 For example, with a single delay line, 256 taps are necessary to provide an intertap 130

delay time of 25 nano seconds and a maximum delay time of 6.4 microseconds whereas when two delay lines are used only 32 taps are necessary. Where 4 delay lines are used, the total number of taps is only 16. However, two large number of delay lines renders difficult the connection thereof. When two delay lines are used to obtain 256 delay times, provision of 16 taps for each gives a minimum total number of the taps.

Although in the foregoing embodiment, the second tapped LC delay line was connected next to the first tapped LC delay line, their order of connection may be reversed.

In the embodiment described above since the same apparatus is used in common for the transmission and reception of the wave the directivities of transmission and reception coincides with each other, thus assuring excellent characteristic. When the elements shown in Fig. 7 are formed on the same printed circuit board, such assembly can be deemed as a high quality delay line thus facilitating its wiring, because the address of the read only memory devices 63 is common for all delay circuits DC_1 to DC_{32} . As calibration of the delay circuits is performed on the printed circuit board together with each electronic circuit element to be used, an accuracy of the delay time is highly enough when they are included in the apparatus. Furthermore, frequency characteristic of the delay circuits is easily extended up to 4 MHz.

Although in the foregoing embodiment the invention was applied to ultrasound diagnosing apparatus comprising transmit and receive circuits, it is possible to apply the invention only for the transmitting apparatus and also it is possible to use a digital apparatus for transmission and to apply the invention only for the receiving apparatus.

Furthermore, although in the foregoing embodiment, driving pulse generators are provided for each ultrasound transducer elements, it is possible to use only one driving pulse generator and apply the output of the generator to the each variable delay circuits.

It should also be understood that the invention is not limited to a sector scanning type but also applicable to a combination of linear scanning and sector scanning systems.

By applying the electronic focusing to the ultrasound diagnosing apparatus described above, it has the great advantage of producing the high quality tomographic images.

Even when a tapped delay line having an ordinary delay time accuracy is used, it is possible to obtain a sufficiently accurate delay time without deteriorating the frequency characteristic, and also it is possible to steer the ultrasonic waves enough accurately for the desired azimuthal direction in the ultrasound transmission or reception operation.

Moreover where a tapped LC delay line is

used as the delay line above described, it is easy to obtain a dynamic range above 100 db so that the circuit elements and peripheral apparatus can be greatly simplified. As the delay line is determined solely by the address of the memory device and since the address is common to all channels, the number of connecting wires can be extremely reduced thus simplifying the control circuit. Since the adjustment can be made for individual channel, it can be made very readily.

Furthermore according to this invention there is an irregularity in the delay time error so that quantization becomes random. This eliminates the regularity of the quantization error. This is advantageous in that the quantization side lobe can be decreased.

It should be understood that the invention is not limited to the embodiments described and that many variations and modifications may be made without departing the true scope of the invention.

For example, Fig. 10 shows another embodiment of this invention. In this embodiment a set of delay circuit DC_1 is constituted by first and second tapped LC delay lines 101 and 102 each having 16 output taps, first and second identical transfer switches 103 and 104, each having 16 inputs respectively connected to the 16 output taps of the delay lines, a memory latch 105 connected to 4 control input terminals A_1 to A_4 and B_1 to B_4 respectively of these transfer switches, and a buffer amplifier 106 connected between the output terminal of the first transfer switch 103 and the input terminal of the second tapped LC delay line 102. These elements are formed on the same printed circuit board.

The scanning control circuit 110 comprises a direction designation circuit 111 that designates the direction of transmitting and receiving the ultrasonic wave, a programmable read only memory device PROM (112) (whose contents can be updated) in which the switch numbers that give delay times sufficiently close to the delay times to be given to respective delay circuits DC_1 to DC_{32} by utilizing the direction designated by the direction designation circuit, and a writing latch designation circuit 112 which write the data in a latch circuit 105 on each printed circuit board at each rate pulse. The output of the PROM 112 is applied to the input terminal of the memory latch 105 of respective delay circuits DC_1 to DC_{32} . With the scanning control circuit 110 described above, the direction designation circuit 111 produces an 8 bit signal 00000000 corresponding to the azimuthal angle θ_{128} of the ultrasonic wave, and the PROM 112 apply a combination of switch numbers to be selected of respective delay circuits DC_1 to DC_{32} to the memory latch of respective delay circuits DC_1 to DC_{32} . In response to the rate pulse from the reference signal generator 31.

the output signal of the writing latch designation circuit 114 is applied to the memory latch 105 to write the output signal of the PROM 112 into the memory latch circuit 105.

With the construction described above, the tap position to be selected of the tapped delay lines of all delay circuits is written in a single read only memory device. Each delay circuit can be readily manufactured at a low cost since the tap position stored in the read only memory circuit can be preserved by a memory latch circuit. Furthermore by modifying the contents of the single read only memory device, change of the scanning direction, provision of delay for focusing and addition of a delay for the other purposes are facilitated.

Programmable read only memory or erasable programmable read only memory are included in read only memory. In this invention, since the contents of read only memories are generally different depending on delay lines, the programmable read only memory or erasable programmable read only memory are extremely convenient for use.

In the invention, described above, various kind of memory device such as read only memory device, memory latch circuit etc. can be used for the memory device used in the each delay circuits.

Instead of forming the address of the read only memory device with 8 bits for designating the 256 directions of ultrasound beam, higher quality of tomographic images can be obtained by an ultrasound diagnosing apparatus which comprises the ultrasound transmitting or receiving apparatus in which 256 directions are encoded with 8 bits out of 10 bits that form the address of the read only memory and remaining two bits are used as the focusing information.

WHAT WE CLAIM IS:-

1. Ultrasound transmitting or receiving scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line, a plurality of variable delay circuits for applying predetermined delay times to driving signals for driving said transducer elements or receiving signals received by said transducer elements, and a scanning control circuit for controlling the directions of transmission or reception of ultrasonic waves by specifying delay times of said variable delay circuits, wherein each of said variable delay circuits comprises tapped analogue delay lines; switches for selecting the taps of said delay lines; and a memory device having a plurality of addresses corresponding to the directions designated by said scanning control circuit, position information of the delay times provided by taps of said delay lines being so stored in the locations of the memory designated by said

addresses that predetermined delay times may be selected.

2. Ultrasound transmitting or receiving scanning apparatus according to claim 1 wherein said tapped analogue delay lines, said switches and said memory device are arranged in a single printed circuit board.

3. Ultrasound transmitting or receiving scanning apparatus according to claim 1 wherein said tapped analogue delay lines comprise a first delay line and a second delay line having an intertap delay time approximately equal to the overall delay time of said first delay line and an overall delay time longer than that of said first delay line and having a delay time necessary to give a maximum deflection angle of the ultrasonic wave.

4. Ultrasound transmitting or receiving scanning apparatus according to claim 1 wherein each said tapped analogue delay line comprise first and second analogue delay lines each provided with 16 taps.

5. Ultrasound transmitting or receiving scanning apparatus according to claim 1 wherein each said tapped analogue delay line comprises an LC delay line.

6. Ultrasound transmitting or receiving scanning apparatus according to claim 1 wherein said memory device comprises a read only memory device.

7. Ultrasound transmitting or receiving scanning apparatus according to claim 6 wherein said memory device comprises a programmable read only memory or an erasable programmable read only memory device.

8. Ultrasound transmitting or receiving scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line, a plurality of variable delay circuits for applying predetermined delay times to driving signals for driving said transducer elements or receiving signals received by said transducer elements, and a scanning control circuit for controlling the directivities of transmission or reception of ultrasonic waves by specifying delay times of said variable delay circuits, wherein each of said variable delay circuits comprises tapped analogue delay lines; switches for selecting the taps of said delay lines; and a memory latch circuit for storing output information from said scanning control circuit, and said scanning control circuit comprises a read only memory device having a plurality of addresses corresponding to the directions of ultrasound transmission or reception, position information of the delay times provided by taps of said tapped analogue delay lines being so stored in the locations of the memory designated by said addresses that predetermined delay times may be selected; a direction command generating circuit for generating that address information of said

read only memory device corresponding to the direction of the ultrasonic waves; and a write latch command circuit for supplying a write latch pulse to said memory latch circuit of said variable delay circuits.

5 9. Ultrasound scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line to transmit and receive ultrasonic waves, one or
10 more driving circuits for driving said transducer elements, a plurality of variable-delay circuits corresponding to said respective ultrasound transducer elements for applying
15 pre-determined delay times to the output of said driving circuits and to signals received by said transducer elements, a scanning control circuit for applying signals to said respective
20 variable-delay circuits to designate the directivity of transmission or reception of ultrasonic waves, means for displaying the received signal passed through said
25 variable-delay circuits, received by said ultrasound transducer elements, each of said variable delay circuits comprising tapped analogue delay lines, switches for selecting
30 the taps of said delay lines, and a memory device having a plurality of addresses corresponding to the directions of transmitting and receiving the ultrasonic wave and in which
are stored positions of taps of said tapped analogue delay lines which give delay times sufficiently closest to the predetermined delay times.

35 10. Ultrasound scanning apparatus according to claim 9 wherein said tapped analogue delay lines comprises a first delay line and a second delay line having an inter-tap delay time approximately equal to the
40 overall delay time of said first delay time and an overall delay time longer than that of said first delay line and having a delay time necessary to give a maximum deflection angle of the ultrasound directivity.

45 11. Ultrasound scanning apparatus according to claim 10 wherein said tapped analogue delay lines each comprise first and second analogue delay lines each provided with 16 taps.

50 12. Ultrasound scanning apparatus according to claim 10 wherein said tapped analogue delay lines comprise LC delay lines.

55 13. Ultrasound scanning apparatus according to claim 10 wherein said memory device comprises a read only memory device.

60 14. Ultrasound scanning apparatus according to claim 13 wherein said memory device comprises a programmable read only memory or an erasable programmable read only memory device.

65 15. Ultrasound scanning apparatus according to claim 9 wherein said tapped analogue delay lines, said switches and said memory device are arranged in a single printed circuit board.

16. Ultrasound scanning apparatus comprising a plurality of ultrasound transducer elements which are arranged along a line to transmit and receive ultrasonic waves; one or more driving circuits for
70 driving said transducer elements; a plurality of variable delay circuits corresponding to said respective ultrasound transducer elements, and having tapped analogue delay lines for applying predetermined delay times
75 to the output of said driving circuits and to signals received by said transducer elements; switches for selecting the taps of said delay lines; a memory latch circuit for storing tap positions information; and a scanning
80 control circuit having a read only memory device having a plurality of addresses corresponding to the directions of transmitting and receiving the ultrasonic waves in which are stored the position
85 information of taps of said tapped analogue delay lines which give delay times closest to the predetermined delay times; a direction command generating circuit for supplying addresses corresponded to the directions of
90 transmitting and receiving said ultrasonic waves; and a write latch command generating circuit which supplies write latch pulse to said memory latch circuit.

95 17. Ultrasound transmitting or receiving scanning apparatus, substantially as hereinbefore described with reference to Figures 3 to 10 of the accompanying drawings.

For the Applicants,
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6 SHEETS

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Sheet 2

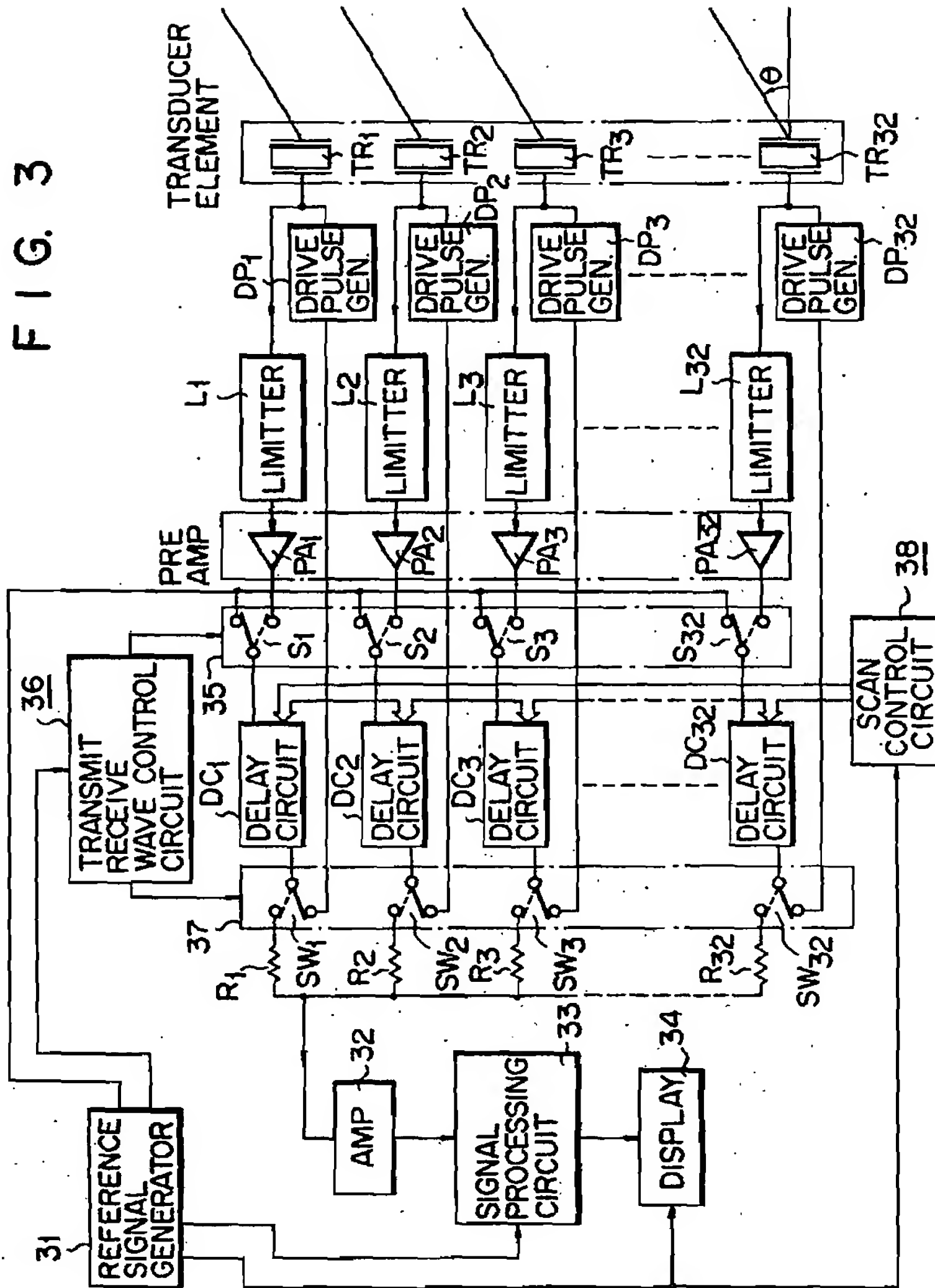


FIG. 6

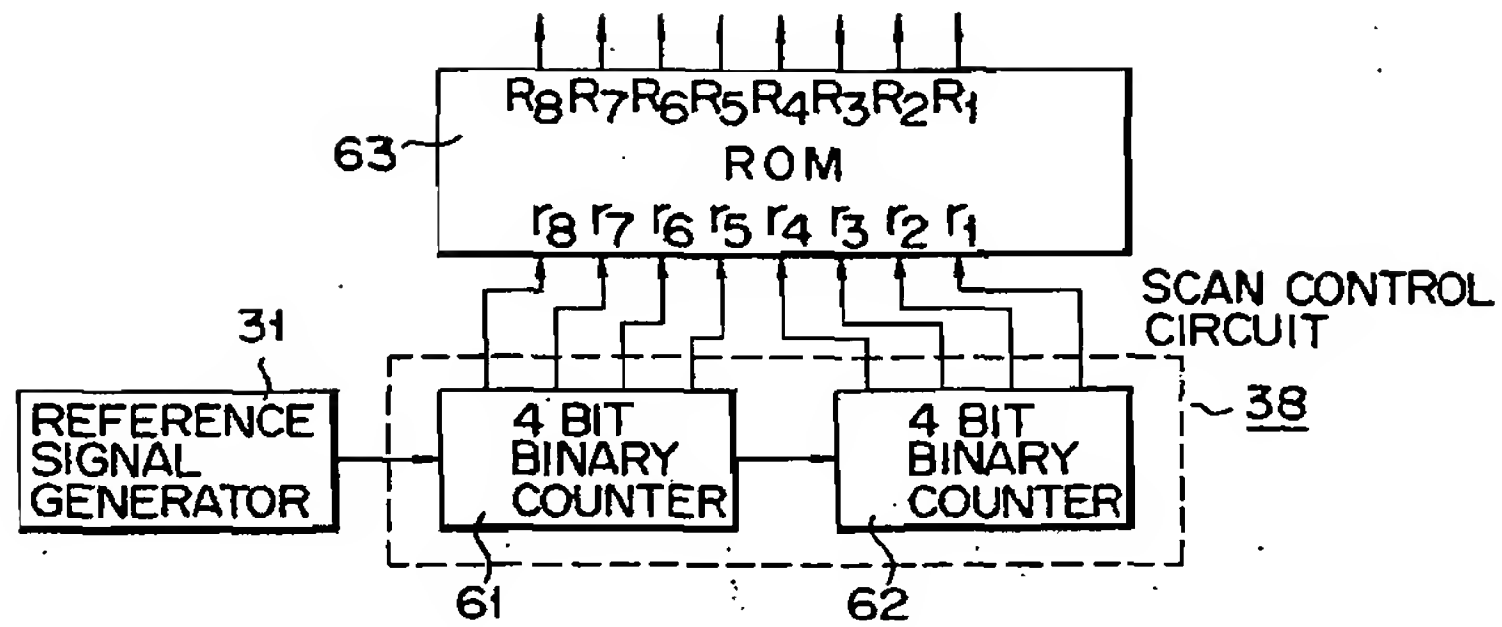


FIG. 7

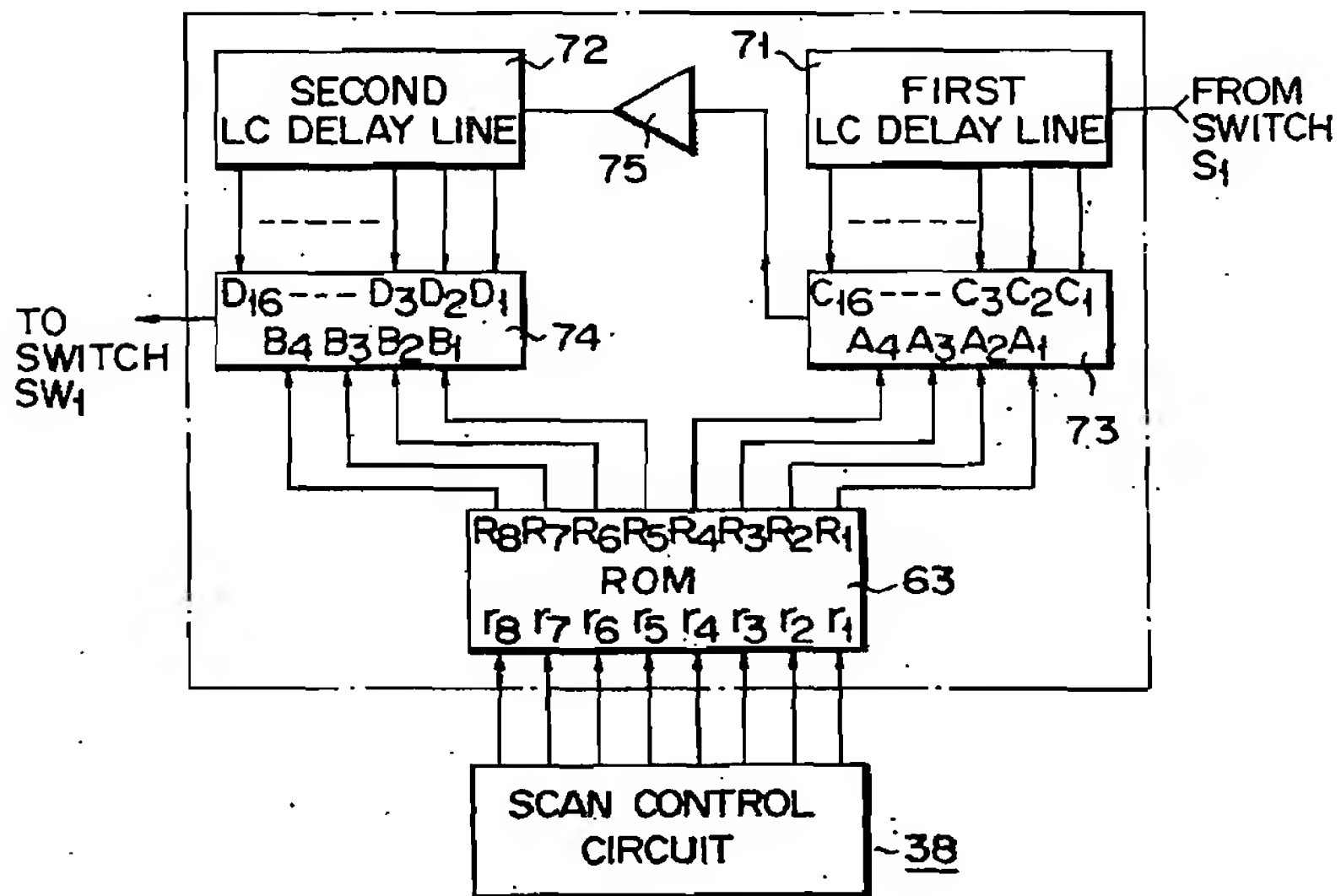


FIG. 8

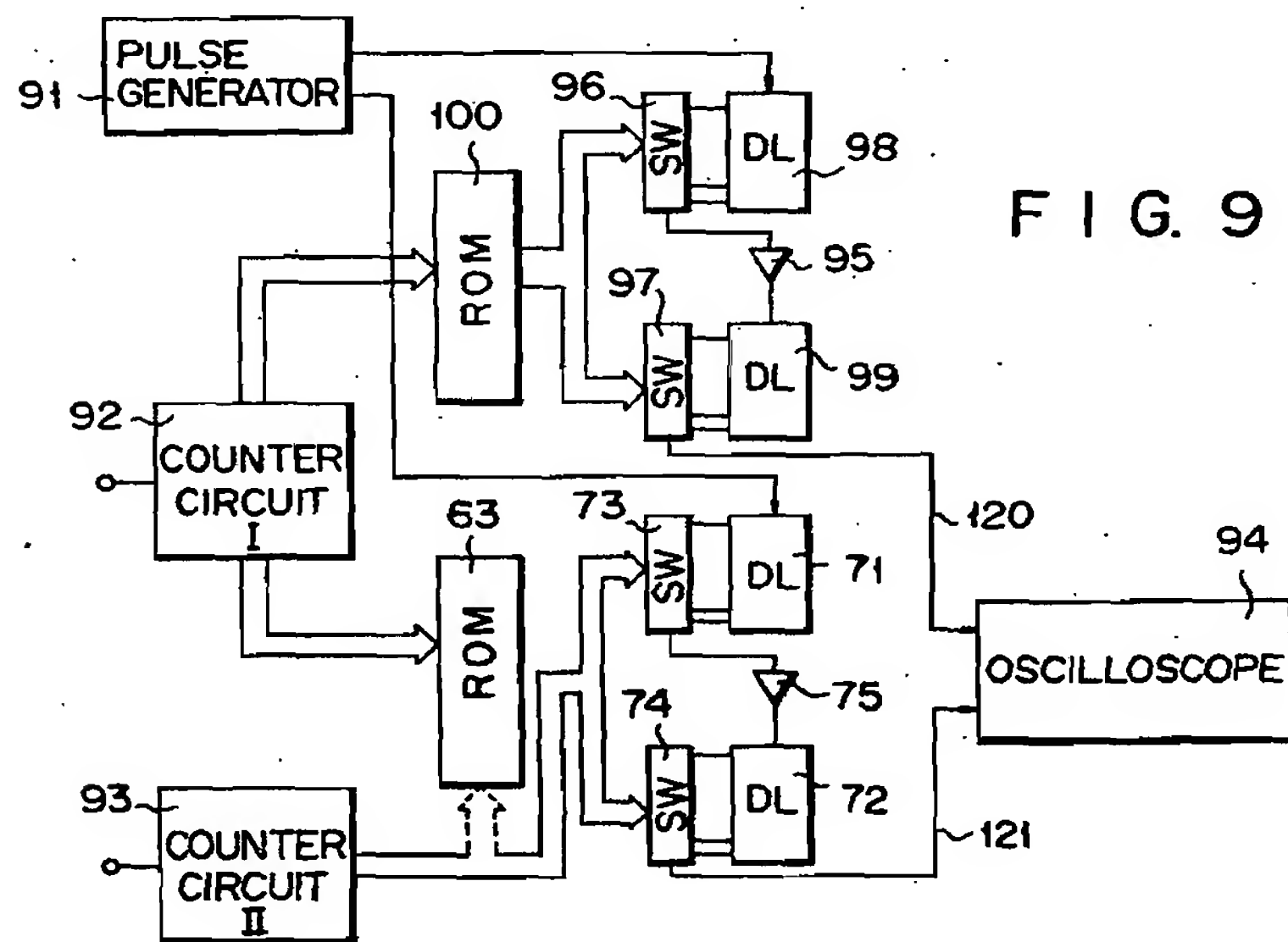
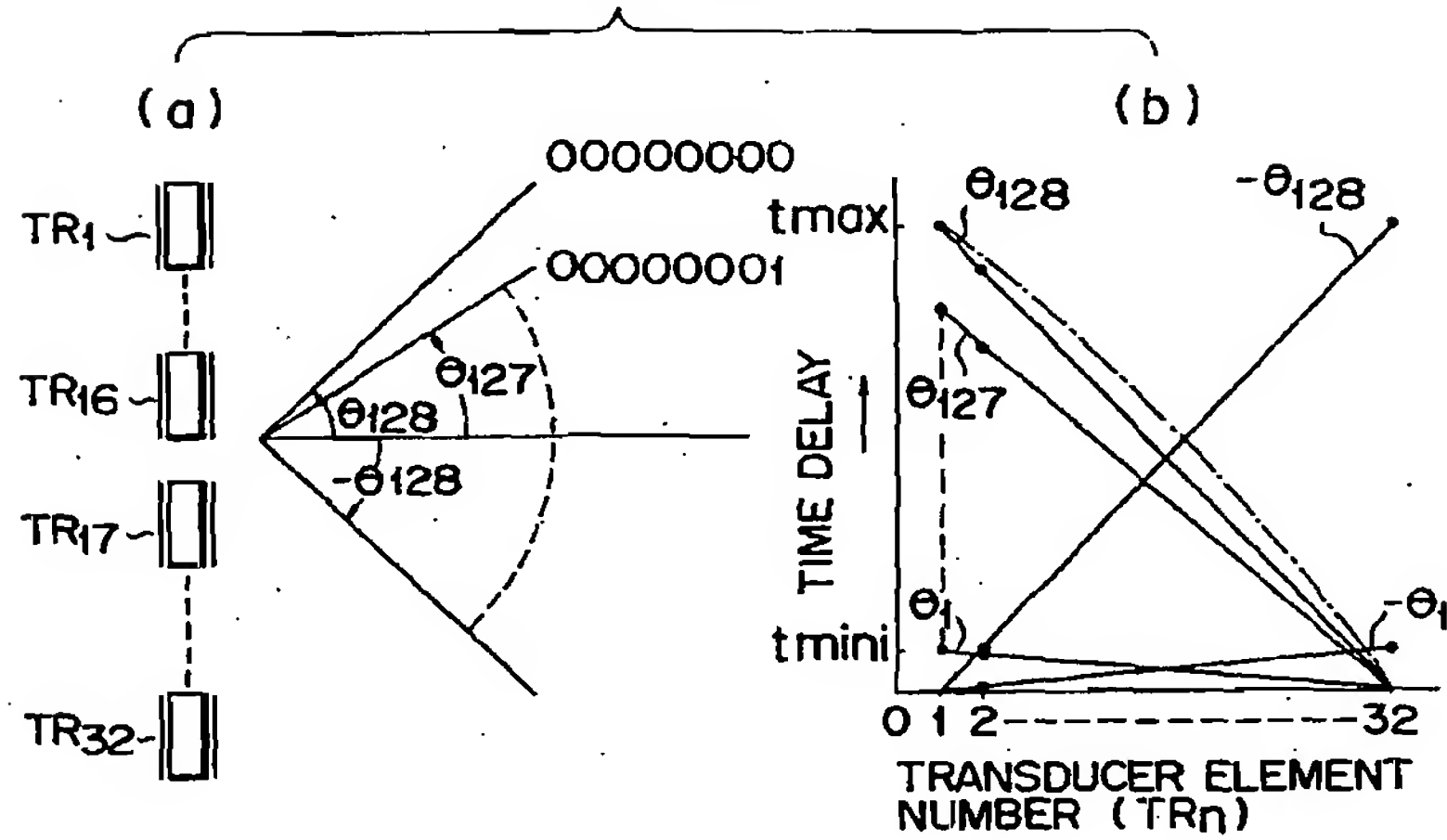


FIG. 9

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Sheet 6

FIG. 10

